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Energy-efficient extraction of fuel from chlorella combined with CO_2 capture

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Abstract

To combine the abilities of lipids extraction and CO_2 capture by algae + IL system, chlorella hydrolysis integrating CO_2 removal by ILs ([bmim][BF_4], [bmim]Cl and [amim]Cl) to extract lipids energy-efficiently was demonstrated in this study. The addition of CO_2 to [bmim][BF_4] can increase the lipids yield from 14.2% to 15.6%. The value of net energy gain increased from 10.4 to 35.9 with the CO_2 addition to [bmim][BF_4] because of the compensated CO_2 capture energy in the algae extraction process.

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Keywords: fuel extraction; chlorella; CO_2 capture; ionic liquid

1. Introduction

Because of the high toughness of bacterial polysaccharide (9 kJ kg^{-1}), fuel extraction is the bottleneck for the commercialize of algae-sourced feedstocks [1]. Compared with traditional acid/base water solutions and organic solvents for cell hydrolysis, ILs are generally stable, effective, environmentally benign, and better product selectivity [2]. Meanwhile, room-temperature ILs were proposed as a potential candidate for CO_2 capture in the last few years [3]. Therefore, it would be interesting to take advantage of the abilities of IL for algae hydrolysis and CO_2 capture in the process of fuel extraction from algae. The chlorella hydrolysis integrating CO_2 removal by ILs ([bmim][BF_4], [bmim]Cl and [amim]Cl) was demonstrated in this study. CO_2 solubility in ILs was measured under the operation conditions of CO_2 capture by ILs (101 kPa, 293 K) and CO_2 release / chlorella hydrolysis (101 kPa, 383 K). The chlorella

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cells hydrolyzed by ILs were observed via transmission electron microscope (TEM). Fuels extraction efficiencies using different IL were compared. Furthermore, the net energy gain from chlorella to lipids, considering energy compensated by CO_2 captured, was estimated.

2. Experimental

The experimental schematic was illustrated in Figure 1. The CO_2 solubility in ILs was measured by a self-built apparatus [4] under the operation conditions of CO_2 capture by IL (101KPa, 20°C) and CO_2 release / chlorella hydrolysis (101 kPa, 110°C). The mixture of chlorella lysis by IL, as shown in Fig.1.c, was sampled for observation *via* TEM (JEM-1400, HITACHI). The contents of biodiesel, as shown in in Fig.1e, were analysed by a gas chromatograph (GC) (9790 Ⅲ, FuLi Analytical Instrument). Methyl undecanoate was used as internal standard substance. Extract mass spectra was obtained by ionization time-of-flight (MALDI-TOF) techniques.

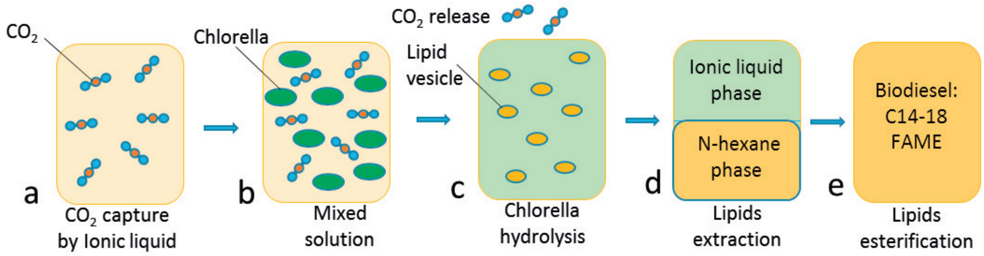


Fig. 1. Experimental schematic.

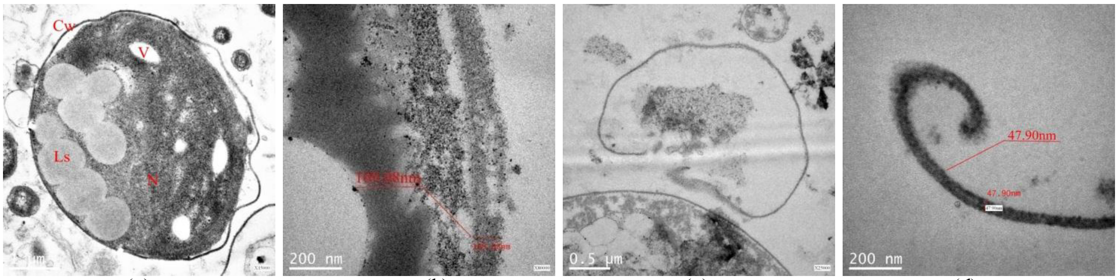
3. Results and discussion

3.1. Chlorella experiments

At a volume ratio of 1:10 (wet chlorella : IL), a species comprising a polysaccharide cell wall (cellulosic algae), was hydrolysed by ILs. The lysate of chlorella + [amim]Cl was observed by TEM. Micrographs of intact chlorella and cells broken by hydrolysis of IL were demonstrated in Fig. 2, respectively. The elaborate structure of intact chlorella such as cell wall (Cw), vacuole (V), nucleus (N) and liposome (Ls) can be observed clearly in Fig. 2. (a). Thickness of the intact cell wall was measured to be 109 nm as illustrated in Figure 2 (b). When wet chlorella was mixed with [amim]Cl, part of the cells were disrupted and cytoplasm flowed out from the cells, as shown in Fig. 2 (c). Thickness of the broken cell wall was 47.9 nm illustrated in Fig. 2. (d). Therefore, IL such as [amim]Cl can hydrolysis chlorella cells effectively.

3.2. Lipid yield

CO_2 solubility in ILs was presented in Table 1. Under the pressure of 101 kPa, CO_2 was absorbed at the low temperature of 293 K and released at the high chlorella hydrolysis temperature of 383 K. Among three ILs, [bmim][BF_4] showed the biggest CO_2 solubility of CO_2 with 3.56 mol% at 293 K and 2.78 mol% at 383 K. Yields of lipids from wet chlorella extracted by ILs and accordingly yields of biodiesel were demonstrated in Table 1. The addition of CO_2 to [bmim][BF_4] can increase the lipids yield from 14.2% to 15.6%. The lipids yield by Soxhlet extractor is 20.8%, which can be roughly used to indicate the total lipids contents in chlorella cells. The value of 15.6% by [bmim][BF_4] thus means that the percentage of extracted lipids is 75%. When CO_2 added to the IL, it reacted with water to form H^+ and HCO_3^-. They may attack on the glycosidic bond. Therefore, an increase in lipids yield by CO_2 addition can be definitely observed for [bmim][BF_4].



(a) (b) (c) (d)

Fig. 2. Ultrastructure of the chlorella cells. (a) intact chlorella cells; (b) wall of the intact chlorella cell (c) chlorella cell hydrolysed by [amim]Cl (d) wall of the chlorella cell hydrolysed by [amim]Cl.

Table 1. CO_2 solubilities, yields of lipids and yields of FAME.

IL	x_a mol‰		x_d mol‰		W_{lipid} [a] %		W_{FAME} %	
	T=293K	P_{CO2}=101 kPa	T=383K	P_{CO2}=101 kPa	+ CO_2	-	+ CO_2	-
[amim]Cl	2.61		0.23		18.6	18.3	14.2	14.3
[bmim]Cl	3.23		0.25		18.1	17.6	14.2	13.6
[bmim][BF_4]	35.6		2.78		15.6	14.2	11.7	10.6

[a]: the lipids yield is calculated by the weight ratio of extracted lipids to dry algae.

3.3. Well-to-station net energy gain

The chlorella extraction by [bmim][BF_4] combining CO_2 capture was employed in the calculation of the net energy gain (NEG) across the "well-to-station" path [2]. Energy consumption and production from chlorella culture to biodiesel combined with energy compensation by CO_2 capture were presented in Table 2. Energy flows for cultivation, harvesting, and transesterification were adopted from the study of Teixeira [2] with wet extraction from nitrogen-starved (Low N). Energy required by CO_2 capture with conventional MEA scrubbing process was calculated to be 3.9 GJ per ton captured CO_2 [5]. The biogas was employed as the feed gas for the calculation of the amount of captured CO_2 [6]. The feed gas was compressed to be 1.2 MPa, and the partial pressure of CO_2 was 0.48 MPa. The electricity energy required by feed gas compression was 0.043 MJ per kg dry algae for work. The corresponding heat energy was -0.044 MJ per kg dry algae for cooling. Those values of 0.043 MJ and -0.044 MJ are much lower than energy compensation by CO_2 captured (1.56 MJ, see Table 2). As shown in Table 2, net energy gain of IL with CO_2 was much higher than that of other campaigns. It should be noted that heat energy cannot be directly compared with electricity energy due to different exergy.

4. Conclusion

The addition of CO_2 to [bmim][BF_4] can increase the lipids yield from 14.2% to 15.6%. The value of net energy gain increased from 10.4 to 35.9 with the CO_2 addition to [bmim][BF_4] because of the compensated CO_2 capture energy in the algae extraction process.

Table 2. Well-to-station net energy gain (all of values are calculated based on 1kg dry algae).

Process		Conventional extraction		Algae hydrolysis	
		Dry	Wet	Normal	+ CO_2
Algae culture and harvesting	Electricity (MJ)	1.5	1.5	1.5	1.5
Drying	Heat (MJ)	14	-	-	-
	Electricity (MJ)	1.4	-	-	-
Lipid extraction	Heat (MJ)	1.2	2.7-6.6	0.4	0.4
	Electricity (MJ)	0.3	1.0-2.4	0.1	0.1
CO_2 desorption	Heat compensation (MJ)	-	-	-	1.56
Lipid transesterification	Heat (MJ)	0.3	0.2	0.2	0.2
Energy Consumption (MJ)		18	5.4-10.7	2.2	0.64
Energy Production (MJ)		23	23	23	23
Net energy gain		1.28	2.15-4.26	10.4	35.9

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Biography

Junchao Huang is a graduate student in East China University of Science and Technology (ECUST), under the supervision of Prof. Shan-Tung Tu. Junchao Huang's research interests are energy efficient extraction of lipids from algae.